DOCUMENT RESUME

ED 380 049 HE 028 203

AUTHOR	Norton, George W.; Paczkowski, Remi
TITLE	Reaping the Return on Agricultural Research and Education in Virginia. Information Series 93-3.
INSTITUTION	Virginia Polytechnic Inst. and State Univ., Blacksburg. Coll. of Agriculture and Life Sciences.
PUB DATE	Oct 93
NOTE	25p.
AVAILABLE FROM	George W. Norton, Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State Univ., Blacksburg, VA 24061-0401.
PUB TYPE	Reports - Research/Technical (143) -- Statistical Data (110)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Agricultural Colleges; *Agricultural Education; *Agricultural Production; Agriculture; *Economic Impact; Educational Economics; Farm Management; Financial Support; Higher Education; *Investment; *Productivity; Research Projects; Rural Extension; School Support; State Universities; Tables (Data)
IDENTIFIERS	*Return on Investment; *Virginia

ABSTRACT

This report focuses upon the economic and other contributions that agricultural research and education have made to Virginia over the past 40 years. Agricultural research, extension, and classroom instruction contribute in the following ways to Virginia's citizens: increased supplies and reduced costs, improved competitiveness, multiplier effects on income and employment in the economy as a whole, food safety and environmental quality, and an educated workforce. Each dollar invested in agricultural research, teaching, and extension programs has generated $4 to $15 in increased farm production over a period of 8 to 15 years. Virginia farm production has increased by 63 percent during the past 4 decades, while the land in farms has declined by 47 percent and labor on farms has declined by 89 percent. These productivity advances to a large extent have been made possible because of the agricultural research, extension, and teaching programs of Virginia Polytechnic Institute and State University. Improvements in productivity associated with investments in these programs account for 46 percent of the $290 million expansion in farm production. Taxpayer dollars are needed to support agricultural research and education because social benefits exceed private benefits and because there is a complementarity between research and education. Appendixes provide a summary of the statistical analysis and a description of the input-output model. (Contains 33 references.) (JDD)

Reaping the Return on Agricultural Research and Education in Virginia

George W. Norton and Remi Paczkowski

Virginia Tech

Virginia Polytechnic Institute and State University
College of Agriculture and Life Sciences
Information Series 93-3

October 1993

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Blacksburg, Virginia 24061-0402

This Information Series of the College of Agriculture and Life Sciences and the Virginia Agricultural Experiment Station provides reviews of scientific literature, historical progress reports, proceedings of significant scientific symposia, and presentation of scientific data in less formal structure.

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Reaping the Return on Agricultural Research and Education in Virginia

Over the past four decades, agriculture in Virginia has undergone a transition from a labor-intensive, resource-based industry to a more capital and information-intensive, science-based industry. Virginia farmers have expanded production by 63 percent while sharply reducing land and labor use. Many factors have contributed to the expansion of production on less land with fewer workers: the initiative and hard work of farm families, low-cost energy, increased amounts of purchased inputs, an improved transportation network, and perhaps most important, the discovery and adoption of improved technologies brought about by agricultural research and educational activities. Yields have increased substantially as new technologies have been adopted. Extension and formal education have enhanced the impacts of these technologies by enabling farmers to employ new methods over a wide range of physical and economic conditions.

This report focuses upon the economic and other contributions that agricultural research and education have made to the Commonwealth of Virginia over the past 40 years. It updates and expands upon a report by Coffey and Norton in 1982. That earlier report, using data from 1949 to 1979, estimated an annual rate of return on investment of 58 percent for agricultural research, 48 percent for extension, and 52 percent for classroom instruction. It estimated that 63 percent of the production expansion in Virginia agriculture over the period 1949 to 1979 was attributable to those three activities. The current study adds data for the 1980s to the earlier data set and re-estimates the economic returns. Other contributions made by these public investments are also highlighted. The main text summarizes the results of the study while details of the statistical analysis are presented in an appendix.

The Nature of Agricultural Research and Education Benefits

Agricultural research, extension, and classroom instruction contribute in the following ways to the citizens of the Commonwealth:

Increased Supplies and Reduced Costs -- Agricultural research and education are investments in future productivity and income growth. Innovative farmers benefit from lower costs per unit of production following their adoption of the new technologies. Consumers benefit through increased quantities of high quality food and fiber at lower prices. Virginia consumers spend less than 20 percent of their after-tax income on food, compared to the 20 to 30 percent that is spent in several other developed countries and the more than 50 percent spent in most of the less-developed countries.

Improved Competitiveness -- Because research and education enhance competitiveness, they help generate income and foreign exchange. Virginia must compete not only in world markets but in domestic markets as well. For example, Virginia competes with the states of Washington, New York, Pennsylvania, Michigan, and West Virginia in apple production; with the midwest states in soybeans and corn; and with Arkansas, Minnesota, California, and Missouri in turkeys. Production of these and other commodities will gravitate to the states with the lowest cost of production and as R & E help lower that cost they strengthen the industry's competitiveness.

Multiplier Effects -- The gains from agricultural research and education are realized in other ways as well. The direct increases in production and income create secondary or multiplier effects on income and employment in the economy as a whole. These benefits stem from the demand for services of input suppliers, and marketing and processing firms, and from the demands of these firms and their employees for industrial and household goods throughout the economy.

Food Safety and Environmental Quality -- Agricultural research and education have also contributed to improvements in food safety and environmental quality. Standards and regulations alone cannot meet all of the concerns that society has about soil erosion, pesticide and bacteria residue on food, and ground and surface water contamination by fertilizers and pesticides. Research and education play vital roles in developing improved technologies, management practices, and incentive structures to reduce these problems at the primary production and processing levels. Because many of the technologies and practices developed do not result in patentable products, the private sector often lacks sufficient incentive to undertake this research on its own. Examples of research results that hold promise for contributing to environmental and food safety improvements are: the development of biological and cultural methods for controlling agricultural pests (often called integrated pest management), of best management practices for controlling soil erosion, of nitrogen-fixing crops, and of improved poultry processing technologies.

Educated Workforce -- Extension and other teaching programs have provided a cadre of educated farmers, government officials, scientists, and agribusiness leaders. These educated people have contributed to the development and adoption of new technologies and other changes that have increased the productivity of Virginia agriculture while enhancing the environment and food safety.

Changes in Virginia Agriculture

The value of agricultural production (measured at the farm level in constant 1982 dollars) has increased from $1173 million to $1915 million, or by 63 percent, over the past 40 years (see Table 1 and Figure 1). While farm output has expanded, farmland acreage has declined by 47 percent and labor by 89 percent. This substantial increase in land and labor productivity is attributable to new technologies that substitute manufactured inputs for land and labor, increase production per unit of input, and permit specialization and reorganization of the farm sector.

Table 1. Production and Conventional Inputs for Virginia Farms 1949-79 in Constant 1982 Dollars (a).

Year	Production (b) ($ mil.)	Labor (c) (thous. man-yrs.)	Land (mil. acres)	Capital Stock (d) ($ mil.)	Current Inputs (e) ($ mil.)
49	1173	325	15.7	2384	689
50	1220	313	15.6	2597	719
51	1228	292	15.4	2690	754
52	1277	278	15.0	3104	811
53	1213	257	14.9	3221	852
54	1323	253	14.7	3132	858
55	1363	245	14.4	3157	914
56	1457	219	14.1	3131	969
57	1198	208	13.7	3084	952
58	1371	203	13.4	2954	971
59	1309	191	13.1	3130	998
60	1340	185	12.9	3175	963
61	1331	187	12.7	3129	966
62	1314	173	12.5	3159	970
63	1146	166	12.2	3175	954
64	1390	159	12.0	3129	982
65	1346	145	11.7	3057	985
66	1167	127	11.5	3136	1001
67	1372	128	11.2	3282	1060
68	1281	119	10.9	3355	1078
69	1324	117	10.7	3254	1097
70	1369	106	10.4	3263	1109
71	1342	104	10.2	3382	1117
72	1376	103	10.0	3366	1103
73	1306	104	9.8	3277	1079
74	1288	81	9.6	3444	1108
75	1350	80	9.6	3258	1125
76	1336	73	9.5	3351	1182
77	1359	53	9.5	3420	1277
78	1533	64	9.5	3173	1327
79	1506	56	9.5	3278	1511
80	1376	56	9.4	3631	1512
81	1661	61	9.4	3681	1490
82	1594	61	9.4	3644	1434
83	1424	42	9.3	3491	1449
84	1741	45	9.1	3371	1425
85	1736	45	9.0	3313	1400
86	1751	40	8.8	3234	1391
87	1788	36	8.7	3131	1394
88	1849	34	8.5	3087	1372
89	1915	34	8.4	3112	1346

Table 1, notes

(a) All data obtained from Virginia Agricultural Statistics, various years.
(b) Gross Income from farming less rental value of dwelling plus inventory changes deflated by index of prices received by Virginia farmers; 1982 = 100.
(c) Annual hours of operator, unpaid family, and hired labor divided by 2000.
(d) The sum of the value of the buildings, machinery, livestock for breeding purposes, and crop inventory deflated by 1982 = 100 index of prices paid.
(e) The sum of the annual expenditures on feed, livestock, seed, fertilizer, miscellaneous and repairs deflated by the respective 1982 = 100 indices of prices paid by farmers.

The amount of capital invested in buildings, machinery, and livestock and crop inventories has increased 30 percent over the period while "current" inputs (annual purchases of feed, livestock, seed, fertilizer, fuels, repairs, etc) almost doubled. Clearly, Virginia agriculture has become more capital-intensive and it has become more economical for farmers to purchase inputs rather than to produce them themselves.

During the 1949 to 1989 period, the number of farms declined by 70 percent. Farm size however, has stabilized in recent years while current inputs, capital, and production per farm have increased (See Table 2 and Figure 2). Yields and quality of commodities have increased as management of farms has improved. In addition to the conventional inputs listed in Tables 1 and 2, non-conventional inputs such as new methods and technologies that arise from agricultural research, extension, and vocational and higher education have also increased over the period (See Table 3). These latter inputs have improved the production per unit of conventional inputs. Many of these new methods and technologies are imbedded in the conventional inputs in terms of quality improvements or enable the farmer to make improved decisions (Coffey and Norton).

The specific measures of non-conventional inputs used in this report are the expenditures on agricultural research, extension, and teaching as defined in the footnotes to Table 3. All are expenditures by the College of Agriculture and Life Sciences at Virginia Tech, its outlying stations, and Extension offices, except the expenditures on vocational agriculture. Vocational agriculture expenditures are public funds spent at secondary schools on vocational agriculture.

The total expenditures for non-conventional inputs listed in Table 3 have risen from $21 million in 1949 to $52.5 million in 1989 (in 1982 dollars). These expenditures are not solely or even primarily from the Virginia General Fund. Substantial amounts of federal appropriations, local appropriations, and special grants and contracts are included. In fact, compared to other states, Virginia ranks in the bottom half in terms of appropriations per person for state agricultural research, per dollar of personal income, per dollar of total state expenditures and per dollar of total research. Although these expenditures are small compared to the value of agricultural production, it will be shown in the next section that they have made a substantial economic contribution to agriculture and to the state over the past 40 years.

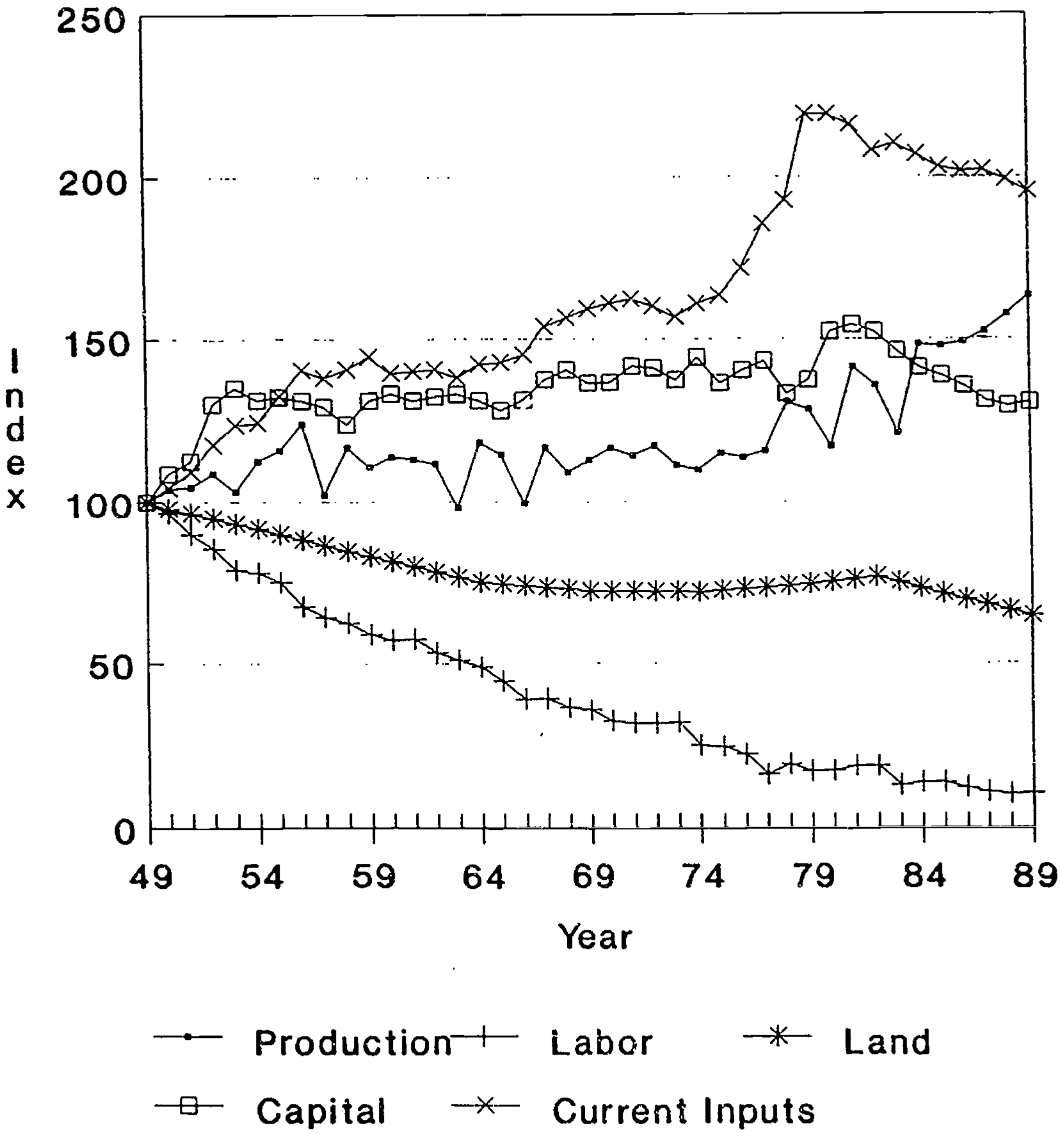

Figure 1. Production and Conventional Inputs for Virginia Farms (1949 = 100).

Table 2. Per Farm Production and Conventional Inputs, Virginia 1949-79 in Constant 1982 Prices (a).

Year	No. of Farms	Production	Labor	Land	Capital Stock	Current Inputs
	(1000's)	($1000's)	(Man-Years)	(Acres)	($1000)	($1000's)
49	168	7.0	1.9	94	14.2	4.1
50	165	7.4	1.9	94	14.2	4.4
51	156	7.9	1.9	98	15.7	4.8
52	148	8.6	1.9	102	21.0	5.5
53	140	8.6	1.8	106	23.0	6.1
54	131	10.1	1.9	112	23.9	6.6
55	122	11.2	2.0	118	25.9	7.5
56	122	11.9	1.8	115	25.6	7.9
57	116	10.3	1.8	119	26.6	8.2
58	112	12 2	1.8	120	26.4	8.9
59	109	12.0	1.8	120	28.7	9.1
60	105	12.8	1.8	123	30.2	9.2
61	100	13.3	1.9	127	31.3	9 7
62	96	13.9	1.8	130	32.9	10.0
63	92	12.5	1.8	133	34.5	10.4
64	88	15.8	1.8	136	35.6	11.2
65	85	15 8	1.7	138	36.0	11.6
66	81	14.4	1.6	141	38.7	12.4
67	80	17.1	1.6	140	41.0	13.3
68	79	16.2	1.5	138	42.5	13.6
69	78	17.0	1.5	137	41.7	14.1
70	76	18.0	1.4	137	42.9	14.6
71	74	18.1	1.4	138	45.7	15.1
72	72	19.1	1.4	139	46.7	15.3
73	70	18.6	1.5	140	46.8	15.4
74	68	18.9	1.2	141	50.6	16.3
75	66	20.5	1.2	145	49.4	17.0
76	64	20.9	1.1	148	52.3	18.5
77	62	21.9	.9	153	55.1	20.6
78	62	24.7	1.0	153	51.1	21.4
79	61	24.7	.9	156	53.9	24.8
80	60	22.9	.9	157	60.5	25.2
81	61	27.2	1.0	154	60.3	24.4
82	62	25.7	1.0	152	58.8	23.1
83	60	23.7	.7	155	58.2	24.2
84	58	30.0	.8	157	58.1	24.6
85	56	31.0	.8	161	59.1	25.0
86	53	33.0	.8	166	61.0	26.2
87	51	35.1	.7	171	61.4	27.3
88	50	37.0	.7	170	61.7	27.4
89	49	39.0	.7	171	63.5	27.5

(a) For definitions and sources see footnotes of Table 1.

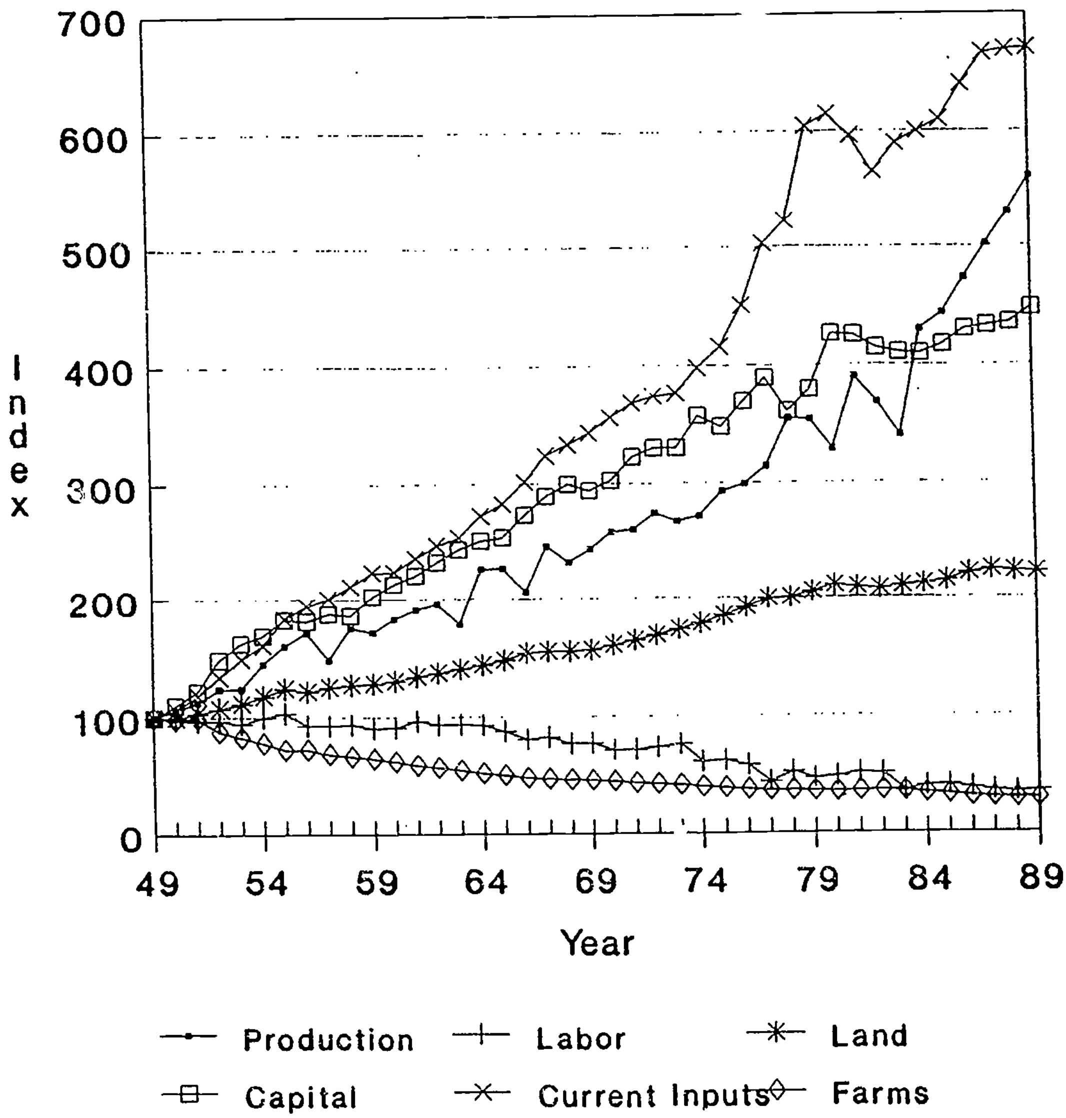

Figure 2. Production and Conventional Inputs per Farm for Virginia Farms (1949 = 100).

Table 3. Agricultural Research, Education, and Extension Expenditures (Constant 1982 Prices) in Virginia 1949-79

Year	Research (a)	Voc Educ. (b)	Higher Educ. (c)	Extension (d)	Total
	($ mil.)	($ mil.)	($ mil.)	($ mil.)	($ mil.)
49	5.9	7.0	3.3	4.7	20.9
50	6.0	7.1	3.4	5.4	21.9
51	6.1	7.1	3.0	5.0	21.2
52	6.5	6.9	2.9	5.0	21.3
53	6.6	6.4	3.0	4.7	20.7
54	7.1	6.3	3.1	4.7	21.2
55	8.2	6.3	3.0	4.5	22.0
56	7.6	6.5	2.8	5.1	22.0
57	8.6	6.6	2.9	5.2	23.3
58	10.2	7.0	3.3	5.6	26.1
59	10.4	6.9	3.0	5.8	26.1
60	10.6	6.8	2.8	5.5	25.7
61	11.1	7.3	2.8	5.4	26.3
62	10.6	7.3	2.7	6.0	26.6
63	11.4	7.3	2.8	6.3	27.8
64	12.0	6.9	3.2	6.3	28.4
65	12.6	7.9	3.2	6.3	30.0
66	13.6	8.5	3.1	6.2	31.4
67	12.9	8.7	3.0	6.7	31.3
68	13.0	8.6	3.0	6.6	31.2
69	12.6	9.7	3.1	7.3	32.7
70	12.3	8.8	2.9	7.9	31.9
71	13.1	8.3	3.4	8.1	32.9
72	12.7	8.0	3.6	9.4	33.7
73	12.8	8.0	3.4	9.9	34.1
74	12.8	10.9	3.5	10.0	37.2
75	13.5	15.8	4.1	10.8	44.2
76	13.5	17.4	4.5	12.7	48.1
77	13.8	17.8	5.7	12.2	49.5
78	13.6	17.9	5.8	8.6	45.9
79	15.6	17.9	6.9	9.3	49.7
80	15.4	17.8	6.0	10.6	49.8
81	16.9	17.4	5.4	10.6	51.3
82	16.5	16.6	6.5	11.5	51.1
83	15.6	16.4	6.9	10.3	49.2
84	15.3	15.4	6.7	10.4	47.8
85	17.1	15.1	7.3	13.5	53.0
86	17.9	14.5	7.5	13.4	53.3
87	18.8	14.1	7.3	13.3	53.5
88	19.6	13.9	7.6	11.6	52.7
89	20.1	13.5	7.4	11.5	52.5

Table 3, notes

(a) Annual expenditures on production agricultural research by the College of Agriculture and Life Sciences, Virginia Tech, deflated by an academic research and development price index (1982 = 100).

(b) Annual public expenditures in primary and secondary schools on vocational agriculture deflated by an academic research and development price index (1982 = 100).

(c) Annual expenditures on teaching by the College of Agriculture and Life Sciences, Virginia Tech, deflated by an academic research and development price index (1982 = 100).

(d) Annual expenditures on agricultural extension by the College of Agriculture and Life Sciences, Virginia Tech, plus the sum of off-campus (county office) expenditures on agricultural extension deflated by an academic research and development price index (1982 = 100).

Estimated Economic Contributions of Research, Extension, and Teaching

A detailed statistical analysis was undertaken to identify the sources of growth in agricultural production in Virginia during the 1949 to 1989 period. The amount of expansion in agricultural production attributable to each input was estimated, as were the economic payoffs to investments in agricultural research, extension, and education (See Appendix 1 for details). Conventional inputs account for only a small portion of the increase because declines in land and labor partially offset the expansion attributable to capital and current inputs. It was estimated that non-conventional inputs of research, extension, and education account for 132 million or 46 percent of the production expansion over the period.

Increase in Production -- The yearly sequences of increases in Virginia annual agricultural production attributable to a one-dollar increase in agricultural research, extension, and classroom teaching expenditures at Virginia are presented in Table 4. For example a one-dollar increase in agricultural extension expenditures increases production during the year it occurs (year 0) by $.21. One year later another increase of $.38 occurs, two years later $.49 occurs, etc., for a total increase over 9 years of $3.87. Similarly, a one-dollar increase in agricultural research increases agricultural production over 12 years a total of $9.10. An increase in agricultural teaching expenditures increases production over a 16 year period by $15.82.

The contribution of investment in agricultural research and education can be explained with a concrete example. Suppose the agricultural extension budget were o be increased by $3.5 million in 1993. This increase would result in an agricultural production increase of $13,545,000 during the period 1993 to 2001 (in other words, 3.5 million x $3.87).

Table 4. Annual Contributions per Added Dollar Expended On Research, Extension, and Teaching

Number of Years After Expenditure	Contribution Per Dollar Expenditure Research	Extension	Teaching
	($)	($)	($)
0	.30	.21	.31
1	.55	.38	.58
2	.75	.49	.81
3	.90	.56	1.01
4	1.00	.59	1.16
5	1.05	.56	1.28
6	1.05	.49	1.36
7	1.00	.38	1.40
8	.90	.21	1.40
9	.75	--	1.36
10	.55	--	1.28
11	.30	--	1.16
12	--	--	1.01
13	--	--	.81
14	--	--	.58
15	--	--	.31
Total	$9.10	3.87	15.82

Annual Return on Investments -- The estimated annual "internal rates of return" on the public investments in agricultural research, extension, and classroom instruction were calculated. These rates measure the annual "real" return on these investments. The "real" means that they are adjusted for inflation. The calculated internal rates of return are:

Research rate of return = 58%
Extension rate of return = 37%
Teaching rate of return = 53%

Each of these returns is higher than rates of return found in other sectors of the economy. They are, however, consistent with the returns estimated for agricultural research and education in many previous studies including the 1982 Virginia Study (See Table 5). Despite the different methods, specifications, and time periods utilized in studies represented in Table 5, the results are remarkably consistent in being well above the rates of return normally considered to be good by private industry.

Table 5. Estimated rates of return to agricultural research for the USA based on econometric analyses.

Study	Commodity	Time Period	Annual rate of return, %
Griliches, 1964	All agriculture	1949-1959	35-45+
Latimer, 1964	All agriculture	1949-1959	Not significant
Peterson, 1967	Poultry	1915-1960	21-25
Evenson, 1968	All agriculture	1949-1959	47
Cline, 1975 (Revised by Knutson and Tweeten, 1979)	All agriculture	1939-1948	41-50+
		1949-1958	39-47+
		1959-1968	32-39+
		1969-1972	28-35+
Bredahl and Peterson, 1976	Poultry	1969	37
	Dairy	1969	43
	Other livestock	1969	47
	Cash grains	1969	36
Peterson and Fitzharris, 1977	All agriculture	1969	43
Evenson et al., 1979	All agriculture	1868-1926	65
	Technology-oriented++	1927-1950	95
	Technology-oriented	1948-1971	93-130
	Science-oriented*	1927-1950	110
	Science-oriented	1948-1971	45
Davis, 1979	All agriculture	1949-1959	66-100
		1964-1974	37
White et al., 1979, personal communication	Aggregate	1929-1941	55+
		1942-1957	48+
		1958-1977	42+
Norton, 1981	Cash grains	1969	31-57
	Dairy	1969	27-50
	poultry	1969	30-56
	Other livestock	1969	56-111
	Cash grains	1974	44-85
	Dairy	1974	33-62
	Other livestock	1974	66-132

Smith et al., 1983	Cash grains	1978	202
	Dairy	1978	25
	Poultry	1978	61
	Other livestock	1978	22
Lyu et al., 1984	All Agriculture	1949-1981	66+
Braha and Tweeten, 1986	All agriculture	1959-1982	47+
Huffman and Evenson, 1989	All agriculture	1950-1982	43
	Crops	1950-1982	45
	Livestock	1950-1982	11
Norton and Ortiz, 1992	All agriculture	1987	30
	Cash grains	1987	31
	Vegetables	1987	19
	Fruits	1987	33
	Other field crops	1987	34
	Poultry	1987	46
	Other Livestock	1987	55

+Return to research and extension combined.

++Defined by Evenson et al. (1979, p. 1103) as research where new technology was the primary objective.

*Defined by Evenson et al. (1979, p. 1103) as research where the primary objective was answering scientific questions related to the production of new technology.

A brief explanation of how to interpret these rates of return is in order. The "internal rate of return" calculation converts the future flow of benefits, irrespective of the number of years over which they are received, to an annualized basis. The time pattern of the annual returns is taken into account as well so that payoffs received during the early years are given more weight than those received during the latter years. To assess where the payoffs to the tax dollar are greatest, these rates of return can be compared against returns on other public investments. In other words, if the Commonwealth has alternative opportunities to earn more than a 30 to 50 percent return annually on its tax dollar, it may want to consider putting its financial resources in those alternatives. However, if not, it can receive a very handsome return by investing in research and education. It should be recognized that these rates of return represent the return, at the margin, to the expenditures in each area, but that research would be worth less without educated farmers and extension of the research results. Likewise, teaching and extension would be worth less without research.

Multiplier Effects -- The estimated direct effect on agricultural production captures only the first- round effects of the investments in agricultural research, extension, and education. Additional "multiplier" effects are also realized in terms of employment, household income, non-agricultural output, and value-added or gross state product. These effects are generated as the changes in the agricultural sector work their way through input markets, processing firms, retail stores, the service sector, etc.

The results from the statistical analysis reported above were used in conjunction with another economic tool called an input-output model to assess these multiplier effects on the state economy as a whole. (See appendix 2 for a brief discussion of the input-output model). The undiscounted impacts of an additional $3 million spread evenly across research, extension, and teaching in the College of Agriculture and Life Sciences at Virginia Tech were estimated to be as follows:

Item	Impact
Agricultural Output	$28.44 million
Non-Agricultural Output	$ 6.59 million
Employment	995 person-years (jobs for a year)
Household Income	$12.12 million
Gross State Product (Value added)	$34.50 million

The above figures illustrate the far-reaching importance of agricultural research, extension, and teaching to the Commonwealth.

Why spend tax-payer dollars? -- Just because agricultural research and education are high-return activities does not necessarily mean that the public sector should do them. Why not leave research and extension to the private sector and let the students pay all of their instruction costs through tuition? After all, the private sector does conduct some research and extension and students already pay about half the cost of their higher education in Virginia.

The answer is that the economic returns calculated above include benefits to society as a whole that exceed those captured by the p sector and by students. For many types of research and extension, a significant portion of the benefits are not captured by the firms conducting the research and extension but accrue to other firms and to consumers. Because the private firms cannot capture all the benefits, they do not conduct enough of these activities. Also, in many cases the risk of unsuccessful research and the length of time required to complete the research discourages private firms even though the potential gains may be high. Research and extension must help a private company sell a product or derive a profit with reasonable certainty relatively quickly, or the company will not make the effort.

Another reason why all research should not be conducted in the private sector is that there is complementarity between research and education. Graduate education in particular cannot be effective when students and teachers are not conducting research. Also, public research and extension can help maintain a competitive structure in agricultural production, farmer input supply, and marketing sectors. Otherwise a small group of firms conducting research may gain too much market power to the detriment of other producers and consumers.

But why shouldn't students pay the full cost of their education? The reason here too is that the social benefits exceed the private benefits. An educated society is a more productive and competitive society in the world market. The resulting economic growth benefits the state and country and not just the student. Also, if students had to pay the full cost, only the wealthy could afford college. This exclusivity of higher education would have major and detrimental social implications.

Summary and Conclusions

The present day multi-billion dollar food and fiber sector in Virginia has expanded both production and productivity significantly during the past four decades. Virginia farm production has increased by 63 percent, whereas the land in farms has declined by 47 percent and labor on farms has declined by 89 percent. A careful statistical analysis indicates that these advances in land and labor productivity to a large extent have been made possible because of the agricultural research, extension, and teaching programs of Virginia Tech. Improvements in productivity associated with investments in these programs account for 46 percent of the $290 million expansion in farm production during the past four decades.

Each dollar invested in agricultural research, teaching, and extension programs has generated $4 to $15 in increased farm production over an 8-to 15-year period. Agricultural research, extension, and education have produced a 37 percent to 58 percent annual rate of return on the taxpayer funds invested in them. Seldom do public or private investments generate more than a 5 to 10 percent real rate of return; research, extension, and education in Virginia are generating returns 4 to 6 times as high.

These programs also generate sizable multiplier effects in the economy in employment, household income, and gross state product. Food costs have been reduced, foreign trade has expanded, and food quality, food safety, and nutrition have been improved. Methods of improving environmental quality have been discovered. A cadre of educated professionals have contributed to better management decisions and new technologies.

With all these benefits one might be tempted to speculate why research, extension, and education have been increasingly squeezed. High rates of return indicate an underinvestment in these programs, not an overinvestment. The answer to this question relates undoubtedly to a combination of several factors. When the need arises to balance the state budget during a weak economy, in the current political climate it may be easier to forego long-term investments in research, extension, and education than to raise general taxes or to cut expenditures on social programs, prisons, etc. The effects of slicing research, extension, and education programs are not as visible in the short run.

Research and extension programs suffer in particular because the general public often does not understand the origins of competitive industries and lower food prices. To many lay people, milk, meat, bread, and eggs come from the store. The linkage between the low price of eggs paid in the store and investments in poultry research at the university are seldom understood by the general public. Research and extension efforts are often viewed as just taking away from teaching time. Their importance as a fundamental engine of growth in the economy is missed by many people. And, faculty who teach, research, and extend are partly to blame. These three programs are highly integrated in graduate education, but undergraduate students are often not made aware by faculty of the extent to which the material presented in class was generated through research and extension programs. Although examination of student evaluations of teachers often finds that the best teachers are also the best researchers, this complementarity across missions is frequently little understood because it is not explained to the public.

The basic conclusion thus is that Virginia's food and fiber system is a major contributor to the economy. The significant increases in production and productivity over the past four decades are largely attributable to complementary investments in agricultural research, extension, and education. The payoff to these investments is much higher than for most other public investments.

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Appendix 1. Summary of Statistical Analysis

Estimation Procedure -- Presented in Table A.1.1 are results from estimating a time-series Cobb-Douglas production function model for Virginia agriculture with public research, extension, and teaching expenditures using ordinary least squares (OLS) with annual data from 1949 to 1989. Details on construction of variables and data sources are found at the end of this appendix. Although the R^2 is high, the OLS estimates are suspect because of their high variance, which indicates a potential problem with multicollinearity. Hence, labor and capital were restricted to their factor shares and Ridge Regression (RR) was used to mitigate the problem. Although standard errors are only approximate with RR, the approximate P -values were low, indicating a likely high degree of significance for most coefficients. A K factor of .06 was selected for the RR, based on stability of the estimates.

Marginal Products and Rates of Return -- Marginal Products and rates of return are presented in Table A.1.2. The marginal product of research (MPR) was calculated from the RR results in Table A.1.1. by using the following formula:

$$MPR = \sum_{j=0}^{m} a_{t-j} \, \overline{n} \, (\overline{Y} / \overline{R})$$

where MPR is the marginal product of research, a_{t-j} is the partial elasticity of production lagged j years, n is the arithmetic average number of farms, $\bar{Y}$ is the geometric mean of agricultural output, $\bar{R}$ is the geometric mean of agricultural research, and j = 0, 1, 2, . . . m is the number of years over which benefits are spread. Analogous formulas were used for extension and teaching.

These marginal products were used to convert the returns to an annualized rate of return. For example, the internal rate of return (r_R) was calculated for research, using the $9.10 marginal product, by obtaining the solution to the following equation:

$$\sum (MPR_{t-j}) / (1 + r_R)^j) - 1 = 0$$

The returns to extension and teaching were calculated similarly.

The marginal product for education was divided by 2 after it was calculated, to account for the fact that agricultural education expenditures and total higher education expenditures are likely to be highly correlated. The coefficient on the agricultural education variable is likely to be overestimated because of this correlation, and because roughly half the courses taken by an agriculture student are nonagricultural courses that provide the background for the agricultural courses (e.g. biology, statistics, english, chemistry, etc.).

Marginal products also may be overestimated if public research spending and private research spending are correlated or if research results spill into Virginia from other states and those spillins are correlated with the generation of Virginia research results. While these factors may have imputed an upward bias to Virginia research benefits, the degree of that bias is difficult to estimate and hence no adjustments were made.

Table A.1.1 Agricultural Production Function Estimates and Variance Inflation Factors, Virginia, 1949-1989

Variable	OLS Model Coefficient	OLS Model P-value	Variance Factors for OLS Model	Ridge Regression Model (k= .06) Coefficient	Ridge Regression Model (k= .06) P-value
Intercept	-3.916			-1.002	
Expenses	0.450	0.06	250.6	0.139	0.00
Capital	-0.293	0.03	108.5	0.18[1]	
Labor	0.179	0.21	38.4	0.25[1]	
Land	0.726	0.30	461.1	0.297	0.00
Rainfall	0.021	0.01	1.4	0.023	0.02
Research	0.063	0.58	42.3	0.069	0.14
Extension	-0.253	0.25	350.1	0.051	0.01
Education	0.629	0.00	69.5	0.278	0.00
R^2	0.9896				
D.W.	0.892				

1) Coefficient restricted to its factor share.

Table A.1.2. Marginal Products and Internal Rates of Return

Variable	Marginal Products	Internal Rates of Return
Research	\$9.10	58%
Extension	\$3.87	37%
Education	\$15.83[1]	53%

1) Adjusted as described in text to account for cost of non-agricultural education.

Variable Definitions

PRODUCTION - Cash receipts from farm marketings + total non-money income - rental value of farm dwellings + net change in farm inventory (Virginia Agricultural Statistics, Virginia Crop Reporting Service). Inflated by U.S. index of prices received by farmers on all farm products, 1967=100 (Economic Report of the President).

EXPENSES - Deflated sum of expenses on feed, livestock, fertilizer, seed, depreciation, repairs and miscellaneous items (VAS, VCRS).

Deflators:

- feed - U.S. index of prices paid for feed, 1967=100;
- livestock - U.S. index of prices paid for livestock, 1967=100
- seed - U.S. index of prices paid for seed, 1967=100;
- fertilizer - U.S. index of prices paid for fertilizer, 1967=100;
- depreciation, repairs, miscellaneous - U.S. index of prices for aggregate production, 1967=100.

All data taken from Agricultural Statistics, USDA.

CAPITAL - Sum of interest on deflated value of buildings, machinery, livestock inventory, crops stored, and working capital.

Interest on buildings:
deflated value of farm structures excluding dwellings (Farm Real Estate Development, USDA, from 1986 Agricultural Statistics, USDA) times mortgage interest rate (Melichar and Waldheger, from 1980, data provided by Jim Ryan from USDA).
Deflator - U.S. index of prices paid for building and fencing materials, 1967=100 (Agric. Statistics, USDA)

Interest on machinery:
-before 1980:
deflated value of machinery in Virginia times ratio of production assets to farm assets (Balance Sheet of Farming Sector, USDA) times non-real estate average interest rate (Melichar and Waldheger);
-after 1980:
deflated value of machinery in Virginia (VAS, VCRS) times non-mortgage interest rate (provided by Jim Ryan, USDA);
Deflator - U.S. index of prices paid for tractors and self propelled machinery 1967=100 (Agric. Stat., USDA);
Depreciation - combined figure for buildings and machinery (VAS, VCRS).

Interest on livestock:
deflated value of livestock and poultry and 1/6 broiler production (Agric. Stat., USDA) times non-mortgage interest rate (Melichar and Waldheger, from 1980 Jim Ryan, USDA).
Deflator - Virginia index of prices received for meat animals, 1967=100 (VAS, VCRS).

Interest on crops stored and working capital:
1/3 of deflated value of crops stored on and off farms (Agric. Stat., USDA) + deflated value of working capital (VAS, VCRS) x non-mortgage interest rate (Melichar and Waldheger, from 1980, Jim Ryan, USDA).
Deflator - Virginia index of prices received for feed, grains and hay 1967=100 (VAS, VCRS).

LABOR - Total number of hours worked during the year by operators, hired workers, and family members divided by 2000 (= number of man-years).

Each component was calculated as average number of hours per week worked by each type of worker (Farm Labor, USDA, from 1980 data rescaled due to incomplete information) times number of workers of that type (VAS, VCRS) times 52 weeks. From 1981, definitions of categories changed.

LAND - harvested cropland +0.5 x pastured cropland + 0.75 x total woodland + 0.25 x (land in farms - total cropland - total woodland). Data coming from Census of Agriculture (U.S. Department of Commerce, Bureau of Census). Values for non-census years were interpolated (extrapolated) linearly.

RAINFALL - Deviation of precipitation in Virginia in July from 50-year mean (VAS, VCRS).

RESEARCH - 12-year Almon polynomial lag of deflated expenditures on research in agriculture. Data for 1938-1966 from Funds for Research at State Agricultural Stations and Other Cooperative Institutions (USDA), from 1967, data provided by Vernon Boggs (VPI&SU).

EXTENSION - 8-year Almon polynomial lag of deflated expenditures on agricultural extension.
Data:
- 1942-1977 from Cooperative Extension Work in Agriculture and Home Economics (USDA),
- 1978-1985 provided by Ellen Danus (USDA),
- from 1985 provided by Vernon Boggs (VPI&SU).

Deflator - see Research

EDUCATION - 15-year Almon polynomial lag of deflated expenditures on vocational education (*) plus teaching expenditures for the College of Agriculture at VPI&SU (Annual Financial Reports, from 1980 provided by Vernon Boggs, VPI&SU).
(*) - Data on expenditures on vocational education:
- 1934-1962 - Latimer,
- 1963-1979 - U.S. Dept. of Commerce,
- 1980-1989 - calculated assuming the real value of support per teacher stayed at its 1979 level. Data on number of teachers in vocational education provided by Bill Camp and Dale Oliver, College of Agriculture and Life Sciences, VPI&SU.

Deflator - see Research.

Appendix 2. Input-Output Model

The essence of the input-output (I-O)model is the technological relationship that the purchases of any sector in the economy depend on the level of output of the purchasing sector. The key variables in the model are the outputs of sectors into which the economy is divided. Sectors are groups of similar businesses or other entities such as households or governments. The heart of the I-O model is the transactions table, which shows the purchases and sales among sectors of any economy. Direct and indirect coefficients can be derived from this basic set of coefficients. These multipliers show the effects of a change in final demand for a given sector on output, income, employment, and value-added in other sectors.

Multipliers can be constructed in various ways, and care must be exercised in their use. In our example we are interested in examining the secondary impacts resulting from a change in agricultural output that results from the technical change induced by research, extension, and education. This examination requires adjusting the basic input-output coefficients in certain sectors associated with production inputs to agriculture, because technical change-induced output increases result in a different set of input demands than a final demand-induced output change. The multipliers used for the Virginia input-output analysis are shown in Table A.2.1. including both the normal or base-run multipliers and those adjusted for the different input demands.

Table A.2.1.: Input-Output Multipliers for Virginia's Aggregate Agricultural Sector (a)

		Multipliers (b)		
	Output	Employment	Income	Value-Added
Base Run	1.519	1.414 (.040)	2.086 (.262)	1.939 (.629)
Adjusted Transactions (c) Matrix	1.232	1.204 (.035)	1.353 (.426)	2.546 (1.213)

(a) These multipliers are based upon a modified input-output model of Virginia constructed by the Regional Science Research Institute. A non-survey model, it was constructed from 1977 Department of Commerce data using the methods described in Stevens et al.

(b) The multipliers are all Type II multipliers. The first multiplier of each pair is the standard I-O multiplier. For example, the employment multiplier for each sector is the total change in employment divided by the initial change in employment in that sector. The multipliers inparentheses are "pseudo-multipliers." They are calculated as the total change in employment (Income, Value-Added) divided by the initial change in output. The employment "pseudo-multipliers" are man-years per $1000 of output.

(c) Multipliers derived following adjustment of coefficients to reflect differences in input demands that arise from output induced by technological change as compared to output changes resulting from exogenous shocks to final demand.